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Practical Considerations Regarding Early Cutoff Irrigation Experiments and Blocked End Simulations

Prepared for the Imperial Irrigation District

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I was involved in a significant amount of work regarding Imperial Irrigation District's (IID) water use in the 1990's as part of the Technical Work Group (TWG), and later as part of the Water Study Team (WST), along with a number of other well-known agricultural and irrigation experts. My curriculum vitae is provided as Attachment 1 to my companion paper on uncertainty.

I have been engaged by IID to review Reclamation's new 2003 Part 417 Recommendations and Determinations in the context of the experimental methods upon which Reclamation relies in stating a cutback of IID's water supply for 2003, in particular the method most commonly referenced as the "early" or "precision" cutoff method, and the method involving "diking" the ends of the fields. This paper provides my conclusions.

Summary and Conclusions

Reclamation, and others they have relied upon, have placed great weight on the early cutoff* experiments of Bali and Grismer (Bali, et al., 1999) and the simulations of blocked ends irrigations by Walker (2003a, 2003b). They conclude that these methods can be easily applied in IID, at little cost, with no significant yield reductions, and limit tailwater to 5%. However, the early cutoff and blocked ends irrigation methods are at far too early a stage in the technological development process to justify any conclusions about overall water savings or costs for these practices in IID. Commercial demonstrations under the range of conditions typical in IID would be necessary before the applicability, water savings and costs associated with these methods could be estimated.

Early Cutoff Irrigation Experiments

Both Reclamation (Jones, 1998b) and the researchers of this method (Bali, et al., 1999) have stated the need for commercial demonstration and verification of the early cutoff irrigation technique on longer border lengths, under typical IID delivery conditions, and under the variety of conditions throughout the Valley.

Yields. The experimental results do not provide sufficient justification for a claim that the early cutoff irrigation technique can be used without yield loss. Yields achieved during the early cutoff irrigation experiments could be considerably reduced in commercial scale applications of

* I have used the term "early cutoff" to refer to this irrigation method, after Reclamation's terminology (Johnson, 2003, page 42). Others have called it by a variety of names, including "precision cutoff" and "reduced-runoff."

the technology. Whether or not this is the case cannot be determined in the absence of commercial field demonstration experience.

Experimental Sudangrass and alfalfa yields declined at a faster rate than Valley-wide averages over the time span of the research. Comparing yields at different locations within the research plots, as did Grismer, et al. (1997), indicates that yield losses attributable to the method could range from about 7% to 12%.

As research yields are generally expected to exceed average commercial yields (Hill, et al., 1983), a favorable comparison of experimental yields to Valley-wide average yields does not signify that there are no yield losses associated with the method. Without specific yield data from the better farmers similarly situated, one cannot say what magnitude of yield loss the experimental results represent.

Early cutoff irrigation experiments are insufficient grounds to conclude that the technique can be applied commercially with no or minimal loss of yield. Even the "worst case" scenario of 5% yield loss (Kleinman, 2003) cannot be supported based on the experimental results at hand.

Water Savings. Experimental results do not justify claims that the early cutoff irrigation technique can reduce tailwater to, as various parties have claimed, less than 2%, or 3%, or 5%. Water supply and other issues suggest that experimental results might not offer a fair indication of the water savings potential of the early cutoff irrigation technique as it would be applied in commercial practice.

Computer simulations reported by Payne and Brown (2003, page 8) using optimal selection of inflow rates and cutoff times achieved 4% tailwater. Payne and Brown (2003, page 5) also cite experience with early cutoff irrigation in commercial practice in IID that resulted in average measured tailwater runoff of 14%. Examination of the early cutoff irrigation results of Bali, et al. (1999) show that adjusting the method to determine cutoff time to eliminate or minimize incompletely irrigated field ends is likely to produce runoff of 5% to 10%, even under experimental conditions.

Commercial water supply conditions are less flexible and more variable than experimental conditions during at least the first two years of the research trials. These differences can reasonably be expected to cause the commercial users of early cutoff to experience a wider variation in runoff amounts and incompletely irrigated borders (especially for the last set) than did the experimental plots. Any attempts by the farmers to mitigate these effects would result in higher costs, for more intensive management of the irrigations, and possibly for additional on-farm regulating reservoirs.

Water supply differences between the early cutoff irrigation experiments and commercial practice are significant. The researchers themselves (Bali, et al., 1999, page 28) suggest that additional work is needed to verify the applicability of this method to commercial fields under conditions where irrigation water deliveries are set for either 12 or 24-hours as is common in the Imperial Valley.

Differences between the conditions of the experimental plots and commercial practice in the areas of water supply flexibility and variability, multiple set irrigations, and management response to dry field ends are all reasons to expect increased water uses for possible canal spills, runoff from the final irrigation set, or to eliminate dry field ends. Additionally, if yields do decline in commercial practice of this technology, then additional water may be needed to eliminate, or at least reduce, water stress. If possible yield declines are salinity related, then extra water may be needed for periodic additional leaching. All of these should be figured into estimates of possible net water savings.

Costs. The cost estimates prepared by Kleinman (2003) and Payne and Brown (2003) assume that the early cutoff irrigation method could be adopted by commercial IID farmers with very little change from the way it was used during the experimental trials. However, differences in conditions for the research experiments and for commercial farmers in IID suggest that these cost estimates fail to include some significant cost considerations for commercial use of the early cutoff irrigation method. These include:

Credit is given for larger tailwater reductions than may be achieved in commercial practice
Inadequate consideration is given to related additional uses of water
Inadequate consideration given to potential yield losses
Insufficient costs for the "greater attention" required to successfully implement this method
Insufficient costs for irrigation labor for night time shift differentials
No costs included for on-farm regulating reservoirs
No costs included for additional training and education
No costs for the type of demonstration and extension program requested by Reclamation
No costs included for irrigation district support

Thus their cost estimates provide insufficient justification for Reclamation's claim that the "early cutoff practice is simple and inexpensive" (Johnson, 2003, page 52).

Blocked Ends Simulations

That Walker (2003a, page 5) was able to simulate adequate leaching with only 5% tailwater in computer runs, by adjusting inflow rates, set times, and by leveling the lower end of the fields does not prove that this same tailwater limit could be achieved in commercial practice. Walker's simulations of delivery rates above and below the "design" value show that even in simulation, controlling tailwater to a 5% limit is only possible if the irrigator adjusts the cutoff times to match the actual delivery rate.

Deciding when to activate the scald release for blocked ends depends on knowing how long water may pond without crop damage, and on how long it will take the ponded water to drain off the field once the release is activated. The modified (reduced) slope on the bottom of the fields will slow this drain-off process. Given the great potential for scald damage with blocked ends, irrigators will tend to activate the scald release earlier rather than later.

Simulated tailwater estimates are better characterized as a lower bound on what may be achieved under ideal conditions, rather than an upper limit on the tailwater that should be tolerated when blocked ends are implemented in practice.

Until the blocked ends technique is demonstrated in commercial fields, under realistic soil, field scale, water supply and irrigation labor conditions, there is no way to quantify the tailwater that may reasonably be expected with this method. Differences between the ideal conditions inherent in blocked ends simulations and the less flexible, more variable conditions encountered in commercial practice are significant. It is unlikely that the 5% runoff rate hypothesized by Walker, or assumed by Payne (2003b) would be achieved in commercial practice.

Conclusion

The early cutoff and blocked ends irrigation methods are at an early stage in the technological development process. Results from these efforts cannot justify any conclusions about overall water savings or costs for these methods in commercial practice in IID. Commercial demonstrations under the range of conditions typical in IID would be necessary before the applicability, water savings and costs associated with the early cutoff irrigation method could be estimated. The blocked ends simulations provide merely computer modeled results, and would require confirmation by research experiment and commercial-scale demonstration before any performance or cost claims could be substantiated.

INTRODUCTION

Reclamation (Johnson, 2003) has determined that the predicted diversion requirement for the Imperial Irrigation District (IID) is 2,824,100 acre-feet for 2003. Of this, the tailwater component is calculated as 15% of on-farm deliveries. As part of the justification for its decision, Reclamation cites directly, or indirectly through other cited sources, the early cutoff irrigation experiments of Bali and Grismer (Bali, et al., 1999; Bali, et al., 2001; Grismer and Bali, 2001), and to a lesser extent the blocked end simulations of Walker (2003a, 2003b).

Reclamation (Johnson, 2003) summarized the significance of the early cutoff irrigation experiments by noting that:

> "based on field trials, tailwater can be reduced to less than 5%, with little if any impact on crop yields." (page 41)
>
> "Reductions in tailwater can be achieved quickly and at little or no cost. ... One of the single most important methods involves using early cutoff irrigation methods on-farm - which requires farmers to cease irrigating fields before the water begins to flow off the lower end of the field." (page 42)
>
> "This early cutoff practice is simple and inexpensive and minimizes [tailwater] and [scalding]" (page 52)

A summary of the comments from other Reclamation-referenced sources about the early cutoff irrigation experiments is given in Table 1.

Table 1. Comments About the Early Cutoff Irrigation Experiments of Bali and Grismer

Source	Comment
Franzoy (2003)	[Early cutoff irrigation] is a simple and easy practice to implement (page 11). There is evidence from studies in the Imperial Valley that crops grown on the clay soils can be successfully irrigated with tailwater runoff of 5% or less (page 20).
Jensen and Walter (2003)	The most common and economical way to limit surface runoff is to terminate water application in a timely manner [as in the early cutoff irrigation method] (page 10).
Kleinman (2002)	Initial investigations indicate that early cutoff strategies in the irrigation of alfalfa could reduce tailwater runoff to less than 2% … The net cost to the farmers is estimated in the range of $25 per acre foot (page 1).
Kleinman (2003)	Based upon the results of the study, tailwater on Alfalfa Hay was reduced to less than 2% with no loss in hay yield or quality, in comparison to countywide averages. A companion study for Sudan Grass hay resulted in almost no tailwater runoff and no reduction in crop yield. ... For this analysis, 3% tailwater is assumed to provide a margin for error. ... subsequent field trials have shown slight yield losses (2-3%). ... for this analysis, a 5% yield loss is applied (page 2). The net economic costs of the Early Cutoff Strategy are estimated to [range from] $9.11 per acre [wheat] to $23.71 per acre [alfalfa hay] (page 3).
MWD (2003)	… reduced-runoff irrigation was proven to be extremely effective on the heavy cracking clay soils of IID (page 29). ... field studies have successfully demonstrated that alfalfa and Sudan can be successfully produced in high clay content soils of the IID with tailwater runoff less than 5% using simple "reduced-runoff" irrigation systems (page 32). Precision cutoff (Reduced-runoff) technique could reduce tailwater to 5% at a cost of $4.00 per acre per year (page 42, table 2).
Payne (2003a)	Tailwater losses were completely eliminated in one study and were reduced to less than 2% in the other, using only improved management practices with no capital costs for system upgrades. Crop yields were at least as large as area average and in some cases were slightly increased. … There is no additional cost for this practice since the irrigator is already in the field to care for the water (page 8)..
Payne and Brown (2003)	[Early cutoff irrigation] resulted in reducing tailwater to less than 2% without affecting alfalfa yield ... [and] reduced tailwater to almost zero with no effect on the Sudan yield ... the technique has little additional cost to the farmer (page 7).
WAC (2003)	In a 3-year study ... tailwater runoff was reduced to less than 2% ... with no loss in alfalfa yield or quality in comparison to countywide averages (pages 13-14). There are several alternative (and available) technologies, which can be appropriately and effectively utilized ... [including] the application of improved irrigation management [i.e., early cutoff irrigation] of cracking-clay soils (page 151).

Reclamation (Johnson, 2003) summarized the significance of the blocked ends technique by noting that:

> "The ends of the rows (furrows) can be blocked to back water up the furrow at the bottom of the field. The ends of the rows can be opened after a specific time period to allow water to flow off the field." (page 53)

A summary of the comments from other Reclamation-referenced sources about the blocked ends technique simulated by Walker is given in Table 2.

Table 2. Comments About the Blocked Ends Technique Simulated by Walker

Source	Comment
Franzoy (2003)	The ends of the rows (furrows) can be blocked to back water up the furrow at the bottom of the field. The ends of the rows can be opened after a specific time period to allow water to flow off the field. (page 12)
Payne (2003a)	… a small amount of earthwork may accompany this practice … the only tailwater that might possibly spill under this arrangement would be from the last set to be irrigated. Under proper field conditions, this practice can reduce tailwater to less than an average of 2% … [at a cost of] about $4.00 per acre (page 8).
Payne (2003b)	… Walker's [simulations] showed that it is possible to allow no more than 5% tailwater loss, improve the leaching opportunity of the irrigation, and limit field reorganization costs to a practical level (page 3).
Payne and Brown (2003)	Under proper field conditions [blocked ends] can substantially limit tailwater losses. Care must be taken to not scald crops ... [one must] release water from each border as needed to minimize [scalding] (page 10).
MWD (2003)	... simulations [showed] that it is practical to achieve 95 percent irrigation infiltration uniformity in the high clay content IID soils using blocked end irrigation systems (page 32). The blocked ends technique could reduce tailwater to 5% at a cost of $0.35 per acre per year (page 42, table 2). … simulations [by Walker] showed that … it is possible to meet these criteria [5% tailwater, improved leaching and limited field reorganization cost] on IID farms at a reasonable cost (page 43).

It is clear that Reclamation, and others considering possible reductions of tailwater in IID have concluded that the early cutoff irrigation experiments and blocked ends simulations have proven that use of these technologies is practical under commercial conditions in IID, and have proven that the results of commercial use will be similar to experimental or simulated results. Because of the significance placed on these studies by Reclamation and others, a review of the early cutoff irrigation experiments and blocked end simulations was initiated.

As will be explained in this paper, the early cutoff and blocked ends irrigation methods are at far too early a stage in the technological development process to justify any conclusions about overall water savings or costs for these practices in IID. Further, sufficient proper controls have not been utilized by researchers in the early cutoff irrigation experiments, making determinations of the results to be expected in commercial practice very speculative at best. Commercial demonstrations under the range of conditions typical in IID would be necessary before the applicability, water savings and costs associated with the method could be estimated. The blocked ends simulation provide merely computer modeled results, and would require confirmation by research experiment and commercial-scale demonstration before any performance or cost claims could be substantiated.

EARLY CUTOFF IRRIGATION EXPERIMENTS

Procedural details and results of these experiments are given in Bali, et al. (1999), Bali, et al., (2001) Grismer and Bali (2001). Of the alfalfa experiments, Bali, et al. (2001) say:

> " ... tailwater was reduced to <2% ... with no loss in hay yield or quality in comparison to countywide averages. Soil salinity [increased] ... particularly in the lower 15% of the border checks ... However, disking, a single leaching irrigation

and sweet corn production after termination of the alfalfa were adequate to reclaim the soil (page 123)."

Of the Sudangrass experiments, Grismer and Bali (2001) say:

> " ... the reduced-runoff method resulted in satisfactory crop yields, practically no tailwater runoff, and a slight decrease from the initial average soil salinity (page 319)."

Technology Development and Transfer

Do Research Results Indicate Expected Results Under Commercial Practice?

The process of technology development and transfer to commercial practice consists of many activities, accomplished over time. The following four stages represent a simple categorization of these activities:

1. Conceptual and theoretical development
2. Research experiments
3. Commercial-sale demonstrations
4. Commercial practice of the technology

At each stage, the technology may be refined or adjusted based on information gained during the preceding stage. The environment surrounding implementation of the technology is different during each stage, so results obtained at each stage do not necessarily apply (without modification) to the next stage.

Conceptual and theoretical development will identify and apply the appropriate scientific and mathematical principles, and may result in computer models or suggested field practices. Theoretical results usually don't consider such real world factors as differences across space and time of important properties, or the imprecision likely in the measurement or estimation of key values, or the possibility that simplifying assumptions are "too simple" for real world conditions. Comparing theory against field measurements can provide a check that such real world factors are not so significant that they invalidate field application of the technology.

Examples of Stage 1 work include the Grismer and Tod (1994) volume-balance-based method to predict the cutoff time necessary to minimize runoff, and the work of Bali and Grismer (1995) to simulate irrigation performance characteristics based on the Kostiakov and modified Kostiakov infiltration equations. In both cases, the theory was checked against field measured results. In neither case did field results match the theory *exactly* - that is to be expected. In the former case, the match was close enough that further use of the method was deemed justified, and in fact, that method was used in the early cutoff irrigation experiments conducted later by Bali and Grismer. In the latter case, however, the simulated performance values did not match well the field measured values. The workers concluded that modification of the infiltration function to account for the presence of cracks in the soil was needed.

Research experiments (Stage 2 work) provide some verification that the impacts of real world factors are not so significant that they invalidate field application of the technology. However, differences between typical commercial conditions and the scale, management intensity and other characteristics unique to the experimental site represent another level of real world factors that might cause the technology to perform differently in commercial practice than it did in the research experiment. So some commercial demonstrations (Stage 3 work) is generally necessary in the technology transfer process.

Bali and Grismer themselves recognize the need for commercial demonstration of the early cutoff irrigation technique. Their statements include the following:

> " ... additional field studies conducted on [2,500 foot] border lengths may be warranted." (Grismer and Bali, 2001, page 322)
>
> "Additional work is needed to verify the applicability of this method to commercial fields and under conditions where irrigation water deliveries are set for either 12 or 24-hour orders as is common in the Imperial Valley." (Bali, et al., 1999, page 3)
>
> "The objective of this Amendment [a proposal for additional work] is to expand the current project to include commercial fields. The main focus of this study is to develop and demonstrate the use of a volume balance method to predict irrigation cutoff time and to reduce surface runoff to approximately 5% or less of the applied water. ... The specific objectives of this Amendment are: ... 7- Develop a relatively simple approach to predict irrigation cutoff time from pre-determined soil moisture measurements for light and heavy soils of the Imperial Valley." (Bali, et al., 1997, page 2-3)
>
> "The objective of the attached amendment is to expand the current project to include commercial fields. ... The focus of this proposed expansion is to evaluate the potential risks associated with the adoption of our runoff reduction method. ... The budget of the attached amendment covers the costs of studying eight alfalfa and Sudangrass fields ranging in size from 30-80 acres per field." (Bali, 1997, page 1)

Reclamation has also expressed the need for commercial-scale verification of the early cutoff irrigation technique:

> "More emphasis should be put on an application of this technique in the Imperial Valley. We would like to see more evidence of progress in this area." (Jones, 1998a, pages 1-2)
>
> "We question the value of expanding this project to commercial fields in the same format as the original project. However, we are interested in discussing a different approach ... a demonstration and extension program that would take the cutoff time technique and apply it throughout the Imperial Valley with cooperating growers." (Jones, 1998b, page 1)

Earlier experiences support the desire of the researchers and of Reclamation to supplement the research experiments with commercial demonstration and extension activities. For example, Hill, et al. (1983) note that alfalfa yields as experienced under average high yield research situations should be greater than attainable farm field yields, and that attainable farm yields would be greater than expected [actual] alfalfa yields on the farm. Thus the yields achieved during the early cutoff irrigation experiment could be considerably reduced in commercial scale applications of the technology. Whether or not this is the case cannot be determined in the absence of commercial field demonstration experience.

The runoff reduction values achieved during the early cutoff irrigation experiments may not be transferable to conditions of commercial practice. Border lengths twice as long (~1/2 mile) as those used during the early cutoff irrigation experiments (~1/4 mile) are sometimes used on heavy cracking clay soils in IID (Bradshaw, 2003; Franzoy, 2003). Cutting one-half mile irrigation runs into one-fourth mile runs could involve significant cost, up to$528 per acre. Cutting one-half mile runs into one-quarter mile runs is not justified (Franzoy, 2003, page 13), so these longer runs are not likely to be eliminated. Additional field studies are needed to verify the utility of the early cutoff irrigation method on longer border lengths (Grismer and Bali, 2001, page 322).

Payne and Brown (2003, page 5) cite experience with early cutoff irrigation practice in IID. Over a two-year period between 1982 and 1984, tailwater was monitored on almost 15,000 acres using the early cutoff technique. Payne and Brown note: "During the program, the average measured tailwater spill was 14 percent."

Research on approximately 15 acres for 3 years produced tailwater values below 2%. However, commercial use of a similar irrigation practice produced tailwater values of 14%, fully an order of magnitude larger.

As another example, consider the use of tailwater recovery technology in IID. In theory, all tailwater can be captured and reused by such systems. In its analysis, the WAC (2003, Table VI.14, page 145) calculates water savings due to tailwater recovery systems as 100% of expected tailwater. For a 5-crop rotation (alfalfa-alfalfa-alfalfa-wheat-lettuce), they calculate that a tailwater recovery system would save 3.73 acre-feet per acre for the rotation, or 0.75 acre-feet per acre per year. Yet the IID (1996) study indicates that the Conservation Verification Consultants (CVC) studied 21 tailwater recovery systems serving 6,268 acres (average 298 acres each) operating during 1995, and estimated their water conservation at a lower figure, 0.51 acre-feet per acre per year (page 45). The same IID study later estimates (page 75) that tailwater recovery systems could capture 67% of available tailwater. Bali and Gonzalez (1997) cite estimates that tailwater recovery systems could capture about 70% of available tailwater (citing 1990 work by Boyle Engineering).

So commercial scale results may well differ from theoretical predictions or research experiments. A number of infrastructure and procedural details of the early cutoff irrigation experiments differ from conditions of commercial practice. (These will be discussed further in the following sections of this paper). Recognizing these differences, the irrigation scheduling protocols for the experiments were changed to better represent the irrigation practices of commercial fields in the Valley (Bali, et al., 1999, page 30). Thus, key conclusions drawn from the research experiments (regarding yields, water savings and practicality) may not apply directly to commercial use of this technology.

Yields

Do the experimental results justify claims that the early cutoff irrigation technique can be used without yield loss?

Reported yield results of the early cutoff irrigation experiments are listed in Table 3 and illustrated in Figure 1. Experimental yields have been adjusted to 10% moisture content.

Table 3. Early Cutoff Irrigation Experimental Yields Compared to Imperial Valley Average Yields

	Sudangrass Hay Yield (tons/acre)		Alfalfa Hay Yield (tons/acre)	
Year	Imperial Valley Average	Experimental Results	Imperial Valley Average	Experimental Results
1996	6.36	6.84	7.56	10.51
1997	5.56	5.90	7.56	6.59
1998	4.91	4.84	7.65	6.62
3-year Average	5.61	5.86	7.59	7.91

Source: Bali, et al. (1999)

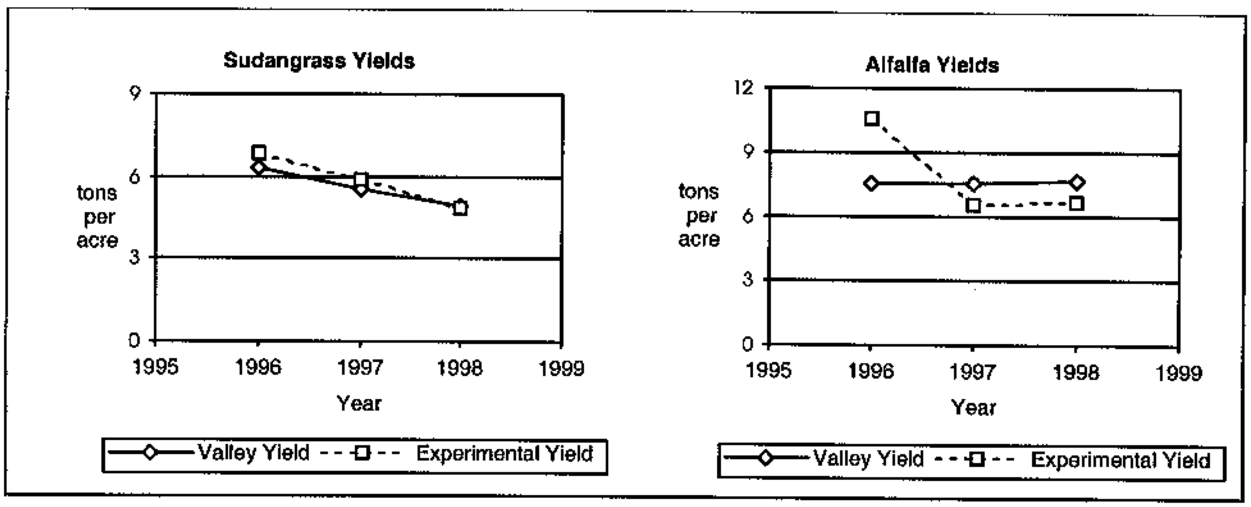

Figure 1. Experimental and Imperial Valley Average Sudangrass and Alfalfa Yields

In the draft final project report (Bali, et al., 1999) the researchers summarized these yield results:

> "Sudangrass yield was not affected by the surface runoff reduction treatment" (page 51)
>
> "For most summer cuttings (June-September), alfalfa yield declines at the lower end of the field. The decline in yield is due to a commination of reduced water application and high salinity (greater water table contributions) at the lower end of the field. ... The overall average yield loss due to yield reduction at the lower end of the field is approximately 1.5% of the expected yield of the entire field." (page

46) [Note: Bali, et al. (2001) define the lower end of the field as the lower 15% of the field (page 125).]

"The effect of reduced surface runoff irrigations on alfalfa yield was only minimal (less than 2% reduction)." (page 51)

As shown in Figure 1, experimental Sudangrass yield declined at a faster rate than Valley-wide average yields over the time span of the research. Valley-wide average alfalfa yields were steady during the time span of the research. In contrast, experimental alfalfa yields declined substantially. The research reports do not provide any discussion or explanation of this fact. It is unknown whether or not some yield reducing mechanism is inherent in the early cutoff irrigation technique. However, the conclusion, based on the comparison of 3-year average yields, that early cutoff irrigation causes no or minimal yield reduction may not be correct.

Since there was no control plot in these experiments, there is no direct measure of how yields using the early cutoff irrigation technique would have compared to yields using conventional irrigation techniques at the same site and under the same conditions. The researchers have taken two approaches to estimating the effects of the early cutoff irrigation technique on yields.

The first approach to making comparisons in the absence of a control plot within the experiments is to compare yields at different locations within the research plots. Grismer, et al. (1997), reporting on the first year of the experiment, compared the average alfalfa yield at the top 1/4 of the field to the average yield at the bottom 1/4 of the field (page 72), and concluded (page 73) that the yield loss due to the early cutoff irrigation technique was about 6.5% of the average yield on the upper 1/4 of the field (6.7% of the average yield on the entire field).

The same approach can be used on the statement of Bali, et al. (2001, page 125) that "The overall average yield loss due to yield reduction at the lower 15% of the field is approximately 1.5% of the expected yield of the entire field." This is equivalent to an average yield on the lower 15% of the field that is 10% lower than the average yield on the entire field, and almost 12% lower than the average yield on the upper 85% of the field. This is illustrated in Table 4 (next page).

If, using the approach of Grismer, et al. (1997), yield losses attributable to the early cutoff irrigation technique are based on yield differences within the plots, then alfalfa yield reductions of 10% to 12% are possible, even under experimental conditions.

The second approach to making comparisons in the absence of a control plot within the experiments is to compare experimental results with some external standard. The researchers compared average experimental yields to average Valley-wide yields, and concluded that the early cutoff irrigation technique caused no (Sudangrass) or minimal (less than 2% for alfalfa) yield losses. But is Valley-wide average commercial yield an appropriate standard?

Table 4. Yield (in Relative Terms) Based on the Statements of Bali, et al. (2001, page 125)

Item	Value
Average yield on the entire field	1.0
Average yield on the lower 15% of the field	0.9
Yield loss on the lower 15% of the field	(0.15)(1.0 - 0.9) = (0.15)(0.1) = 0.015 = 1.5% of 1.0
Average yield on the upper 85% of the field	x
Average yield on the entire field	(0.85)(x) + (0.15)(0.9) = 1
Average yield on the upper 85% of the field	x = [1 - (0.15)(0.9)]/(0.85) = 1.018
Yield loss on the lower 15% of the field relative to Average yield on the entire field	(100)(1.0 - 0.9)/(1.0) = 10%
Yield loss on the lower 15% of the field relative to Average yield on the upper 85% of the field	(100)(1.018 - 0.9)/(1.018) = 11.6%

Since, except for the irrigation technique, management during the experiments ensured that recommended production practices were followed (Bali, et al., 1999, page 31), a more reasonable comparison would be between experimental results and those achieved by the better farmers Valley-wide. Also, since the experimental site is favorably situated (Bradshaw, 2003), in particular with the potential for water table uptake to mitigate possible spot shortages in applied water (Bali, et al., 1999, page 49), a more reasonable comparison would be between experimental results and those achieved by the better farmers similarly, or at least favorably, situated. Since such farmers are expected to achieve yields above Valley-wide averages, experimentally achieved yields probably do exhibit some yield loss relative to this more reasonable standard of comparison.

Without specific yield data from the better farmers similarly, or at least favorably, situated, one cannot say what magnitude of yield loss experimental results represent. However, Hill, et al., (1983), based on a comparison of research experiments and farm field results, assumed that due to differences of scale and cultural practices, research yields for alfalfa were 20% greater than field attained yields. They further assumed that harvesting practices could result to additional reductions so that attainable farm yields for alfalfa would reasonably be 18% greater than expected alfalfa yields on the farm.

Statements from IID farmers - farmers that have themselves tried the early cutoff methodology - also support the possibility that yield reductions could occur as this technique is implemented in commercial practice in IID.

> " ... this method of precise irrigation cutoff has been attempted in the past, but farmers that have used it (myself included) have shown dramatic increases in salinity at the tail end of the field as a result of inadequate leaching. This leads to a corresponding decrease in yields in these areas." (Leimgruber, 2003, page 2)

> "In my experience, in those circumstances where I have run irrigation only to the end of the field, I have noticed an immediate reduction in yields in the tail ends of those fields." (Brundy, 2003, page 2).

Do these calculations and discussions prove that yield effects attributable to the early cutoff irrigation technique are 7% (Grismer, et al., 1997), 10% to 12% (Bali, et al., 2001), or 20% to 38% (Hill, et al., 1983)? No. But they do show that the early cutoff irrigation experiments are insufficient grounds to conclude that the technique can be applied commercially with no or minimal loss of yield. Even the "worst case" scenario of 5% yield loss (Kleinman, 2003) cannot be supported based on the experimental results at hand.

In particular, the early cutoff irrigation experiments of Bali and Grismer are insufficient grounds to for Reclamation (Johnson, 2003) to conclude: "based on field trials, tailwater can be reduced to less than 5%, with little if any impact on crop yields (page 41)," or "reductions in tailwater can be achieved quickly and at little or no cost (page 42)." The impact on crop yields of this technology in commercial practice is unknown, and cost estimates predicated on low yield losses are unproven.

Commercial scale field demonstrations, and more ideally the extensive demonstration and extension program (that would take the cutoff time technique and apply it throughout the Imperial Valley with cooperating growers) proposed earlier by Reclamation (Jones, 1998b, page 1) must be conducted before the yield impact of the early cutoff irrigation technique under commercial practice is known.

<u>Water Savings</u>

Do the experimental results justify claims that the early cutoff irrigation technique can reduce tailwater to:

Less than 2% (Kleinman, 2003; Payne, 2003a; Payne and Brown, 2003; AWC, 2003)?
Less than 3% (Kleinman, 2003)? Or
Less than 5% (Franzoy, 2003; MWD, 2003)?

Reported results of Sudangrass and alfalfa irrigations during the early cutoff experiments are summarized in Table 5.

Table 5. Early Cutoff Irrigation Data [Source: Bali, et al., 2001]

Sudangrass Irrigations			Alfalfa Irrigations		
Date	% Runoff	% of Field Irrigated	Date	% Runoff	% of Field Irrigated
4/16/96	1	99	11/8/95	2	99
5/3/96	1	98	12/4&5/95	7	99
5/24/96	0	95	1/22&23/96	6	100
6/28/96	0	89	3/19/96	4	100
7/23/96	0	93	4/24/96	1	100
8/20/96	0	97	5/17/96	2	99
9/17/96	0	100	6/7/96	0	93
4/21/97	0	95	7/3/96	2	100
5/5/97	2	99	8/2/96	0	97
6/2/97	0	87	9/10/96	0	94
6/20/97	3	100	11/1/96	1	97
7/9/97	3	100	12/20/96	2	100
7/29/97	4	100	2/19/97	2	100
8/20/97	3	100	4/7/97	0	95
9/10/97	4	100	4/28/97	2	100
10/10/97	4	100	5/19/97	1	100
4/15/98	1	99	6/16/97	0	97
4/22/98	0	98	7/11/97	1	98
5/20/98	4	100	7/23/97	1	100
6/17/98	2	100	8/8/97	3	100
7/8/98	2	100	8/19/97	2	100
7/29/98	4	100	9/5/97	1	100
8/20/98	0	91	10/18/97	2	100
			11/14/97	1	99
			2/13/98	1	99
			3/20/98	3	100
			4/17/98	2	99
			4/29/98	1	100
			5/15/98	0	98
			5/27/98	2	99
			6/12/98	2	98
			6/26/98	2	100
			7/14/98	0	97

In the draft final project report (Bali, et al., 1999) the researchers summarized these irrigation results as follows:

> Regarding the Sudangrass irrigations: "With the exception of the first irrigation, the average cutoff distance in 1996 was 889 ft from the border's inlet or approximately 71% of the field's length ... We obtained no runoff at this cutoff distance and surface wetting reached 96% of the field length. In 1997 and 1998, the average cutoff distances for all irrigations except the first irrigation were 868 and 851 ft, respectively, resulting in surface wetting of 98% of the field. We found that the optimum cutoff distance to minimize or eliminate runoff varies from 850 to 950 ft or approximately 70 to 75% of the field's length. ... runoff range[ed] from 1-4% of applied water." (page 37)
>
> Regarding the alfalfa irrigations: "The average cutoff distance for the entire alfalfa growing period was 887 ft from the border's inlet or approximately 71% of the field's length. This is almost identical to the average cutoff distance of the Sudangrass field. We obtained an average runoff of approximately 2% at this cutoff distance and managed to irrigate 99% of the field. Except for the two germination and stand establishment irrigations, the average cutoff distance varied from 797 to 940 ft or from 64% to 75% of the field's length. Flow rate and crack size were the main factors affecting the average cutoff distance. We found that the optimum cutoff distance to minimize or eliminate runoff varied from 800 to 950 ft or approximately 65 to 75% of the field's length." (page 42)

Several considerations suggest that these results may not be a fair indication of the water savings potential of the early cutoff irrigation technique as it would be applied in commercial practice. These include:

Water supply issues
Requirements for irrigators
Multiple set irrigations
Water savings estimates

<u>Water Supply Issues</u>. Irrigators enjoyed a high degree of control over the water supply for the early cutoff irrigation experiments. Farmers in commercial practice do not have the advantages of such control. Bali, et al. (1999, page 30) describe the water supply conditions during the experimental period as follows:

> "During the first year of the study, most irrigation events began between 6-7 am and ended between 5-7 pm. We used a reservoir at UCDREC, that was filled with water from an IID canal the previous day, to start irrigations for approximately 2-3 hours until IID canal water became available at approximately 9 am. At the end of each irrigation excess water ordered from the IID was stored in the reservoir to irrigate other crops at the Center (IID water orders were for either 12 or 24-hour runs). During the last year of the project and in response to issues raised by the PAC, we changed the timing of the irrigations such that we started the irrigation in either the afternoon (4-7 pm) or at night (11 pm - 3 am), and irrigated directly from the IID canal. Such irrigation scheduling better represented the irrigation

practices of commercial fields in the Valley. Except for a few occasions when the IID canal water ran dry during an irrigation event, we had complete control of when to turn the water on or off to the field."

A similar description was included in Grismer and Bali (2001). Bali, et al. (2001), however included no description of the water supply. This has apparently has caused some to conclude, erroneously, that the experiments did not use a reservoir at all. For example, Payne (2003b, page 2) asserts that "there is no mention in the study of water being pumped from a reservoir." However, the project draft final report makes it clear that the description above applies to both the Sudangrass and alfalfa experiments.

There is no discussion in Bali, et al. (1999) of the effects of the change in irrigation protocols for the third year of the experiment, so it is not known how night time irrigation or drawing water directly from the IID canal impacted the implementation of the early cutoff technique.

Any commercial farmers attempting to implement the early cutoff irrigation technique in IID would have to deal with the fact they do not have the complete of control of the water supply that the researchers did during their experiments. There are two basic approaches to solving this problem: terminate the diversion from the IID canal as required by the early cutoff method, or try to handle the diverted water on-farm.

Farmers note that terminating diversions from the IID supply canal is problematic. Kalin (2003) points out that "the Valley's gravity-driven canal delivery system prevents true 'precision' irrigation, as the headgates cannot be shut off as necessary." Cox (2003) agrees: "IID's gravity flow delivery system is not designed for precision shutoff." Gilbert (2003) concludes "Irrigation control techniques must take into account the complex, gravity-flow delivery system. Valley farmers are simply not able to cut the water flow from the headgate at a moment's notice. Even if they could, it is not clear that this would result in any water savings, as an abrupt closing of the headgate would lead to spillwater out of the canals taking the place of runoff from the fields. It simply would change the location of the water loss, not the fact of it."

Grismer (2003, page 10) suggests that instead of terminating diversions at the head gate, the water be handled on-farm: "[the early cutoff] method relies on the ability to control water flows from the head ditch to the field, [so] an allowance must be made for successive irrigation of additional fields downstream or containment of the ordered water on-site (e.g., using a small regulating reservoir)." Neither of these approaches are problem-free.

Successive irrigations of additional fields downstream, when feasible, would probably result in some tailwater (Wallender, in WAC, 2003, page 27): "in order to adequately irrigate the last set, some tailwater may result." But that's only true if the initial water order was sufficient to complete the irrigation on all sets. If the initial order was insufficient, farmers may have to decide between leaving the final set incompletely irrigated, or ordering a "finish head," which is an additional water delivery needed to complete the irrigation of the field the following day. If a portion of the field is under-irrigated, and dry spots remain, the farmer must make a difficult decision whether to risk crop loss on the under-irrigated area, or re-irrigate the much larger area of adequately irrigated crop, and risk over-irrigation damage to those areas of the field that were already properly irrigated (Gilbert, 2003). Application of the finish head may also result in additional tailwater. In any event, these efforts require an increase in the farmer's management time and increased irrigation labor costs in order to properly manage these irrigations and ensure the safety and proper growth of all crops (Cox, 2003).

The use of small on-farm regulating reservoirs, as in the first two years of the early cutoff irrigation experiments, represents a potentially large additional cost to the farmer trying to implement early cutoff irrigations. None of the experts upon which Reclamation has relied for early cutoff irrigation cost estimates considered the potential need for on-farm regulating reservoirs:

The Kleinman (2003) estimate of \$23/ac-ft to implement early cutoff irrigation in commercial practice included no reservoir costs. The \$4 per acre per year cited by Payne and Brown (2003) is based on their observation that "the precision cutoff technique has little additional cost to the farmer, since the irrigator must already be present in the field, on a regular basis, to care for the water." They allocate \$4 per acre per year only to cover a possible shift differential pay for the irrigator who might have to do more, or more difficult, work to implement the method.

Payne and Brown (2003, page 8) raise another key water control issue regarding early cutoff irrigation: "Implicit within the precision irrigation cutoff management practice is the need for selection of the proper water inflow rate to the borders." Walker (2003a) also notes: "An important issue for managing water under a tailwater control strategy is the impact that management and operation of the IID canals and laterals can have on on-farm irrigation performance. A border irrigated farm could be re-designed to achieve high efficiency and uniformity but perhaps would not be operated at these levels unless headgate deliveries would be steady and made at the proper flow."

When the canal delivery rate deviates below the intended rate, slower advance times would lead to greater deep percolation. Deviations above the intended rate would increase advance times and could reduce leaching. In the latter case, Walker concludes that controlling tailwater to a 5% limit is possible, but it would require the irrigator to use different cutoff times than would be calculated for the intended inflow rate.

Thus it is important to note that water supply conditions during at least the first two years of the experiments (pumping from a field reservoir) isolated the experimental plots from normal canal fluctuations (Knell, 1997). The experimental water supply for these years was not typical of surface water irrigation from an open channel canal system in the Imperial Valley (Eckhardt, 2000). There is no discussion in Bali, et al. (1999) of the effects of the change in irrigation protocols for the third year of the experiment, so it is not known how drawing water directly from the IID canal impacted the implementation of the early cutoff technique.

Supply canal fluctuations would present IID farmers with more difficulties in estimating cutoff times (or distances) and managing irrigation water than were evident during the early cutoff irrigation experiments. More intense management of each border's irrigations would be required to adjust cutoff times if delivery rates changed. Or, an unadjusted cutoff time would run greater risk of creating a higher than normal tailwater figure or a higher than normal portion of the field inadequately irrigated.

Cutoff times (or distances) for the early cutoff irrigation method influence decisions such as when to shift the water from one set to the next, and how to match up the water order amount and time with the sets to be irrigated. These cutoffs are based on measurements made during the irrigation for each set. But this is after the farmer has placed the water order. So even if adjustments could be made to optimize the irrigation of a given set, the farmer has limited flexibility to make sure that all the sets served by a given water order are optimized. Adjustments to optimize individual sets can minimize tailwater and incompletely irrigated field ends, but the adjustments may compound to cause a considerably less than optimized irrigation on the final set.

Water supply differences between the early cutoff irrigation experiments and commercial practice are significant. The researchers themselves (Bali, et al., 1999, page 28) suggest that additional work is needed to verify the applicability of this method to commercial fields under conditions where irrigation water deliveries are set for either 12 or 24-hours as is common in the Imperial Valley.

Commercial water supply conditions are less flexible and more variable than experimental conditions during at east the first two years of the research trials. These differences can reasonably be expected to cause the commercial users of early cutoff to experience a wider variation in runoff amounts and incompletely irrigated borders (especially for the last set) than did the experimental plots. Any attempts by the farmers to mitigate these effects would result in higher costs, for more intensive management of the irrigations, and possibly for additional on-farm regulating reservoirs.

<u>Requirements for Irrigators</u>. Experimental use of the early cutoff irrigation technique had the advantages of multiple irrigators in the field during irrigations (Knell, 1997; Bradshaw, 2003), and for the first two years of the experiments, day time only irrigations. Bali, et al. (1999) present no information about how the inclusion of night time irrigation during the third year of the experiments affected irrigator practice, or how the change might influence the commercial implementation of the early cutoff technique.

Labor considerations are, of course, an important concern for valley farmers. IID farmer John Walker (2003) argues that "any tailwater conservation strategy requiring more irrigators, such as irrigation cutoff strategies, may not be possible to implement. The supply of quality irrigators in the Valley is dwindling. Competent, experienced irrigators are extremely difficult to locate. Any conservation strategy that requires more irrigators will necessarily require the employment of less experienced irrigators, which may frustrate the ultimate goal of water conservation."

It is reasonable to expect that a technology such as the early cutoff irrigation method will require training, time to move up the learning curve, and an extension effort before widespread commercial adoption could occur. In 1998, Reclamation proposed a demonstration and extension program that would take the cutoff time technique and apply it throughout the Imperial Valley with cooperating growers. (Jones, 1998b, page 1). Grismer, et al. (1997, page 73) suggest that "with additional education and the support of the irrigation district, [the early cutoff irrigation] method could be used on clay soils throughout the Valley." Grismer (2003, page 16) indicates that "application of the [early cutoff irrigation] method requires some additional training and greater attention during irrigation events. Cox (2003) anticipates that the greater attention required to implement this method, including handling possible finish head orders for the last set, will require an increase in the farmer's management time and increased irrigation labor costs in order to properly manage these irrigations and ensure the safety and proper growth of all crops.

Supply canal fluctuations would require more intense management of each border's irrigations to adjust cutoff times if delivery rates change. Absent this, an unadjusted cutoff time would run greater risk of creating a higher than normal tailwater figure or a higher than normal portion of the field inadequately irrigated.

Night time cutoffs would require irrigators to be in the field at all hours. Often, commercial farmers don't have irrigators working at night. In many cases, there are no irrigators in the fields from 8 p.m. until 6 a.m. the next morning (Bradshaw, 2003). For such farmers, at the very least, arranging for night time irrigators would represent additional costs. Bradshaw (2003) also points out that it is difficult at night to see the water advance in the field to make the cutoff determinations correctly.

The cost estimates of Kleinman (2003) include no allocation for increased labor, nor any allocation for irrigation district support. Payne and Brown (2003) make a minor allocation for labor cost increases. But indications are that commercial adoption of early cutoff irrigation practice will place additional demands on the pool of irrigation labor and the administrative and technical staff of IID. The availability of, or the ability to create, a sufficient pool of trained irrigators for Valley farmers is a critical issue if commercial use of this practice is to proceed. Estimates of the costs of adoption of this technology must be adjusted to reflect this reality.

Multiple Set Irrigations. The difference in scale between the early cutoff irrigation experiments (7-1/2 acres each for alfalfa and Sudangrass) and commercial fields (often an order of magnitude larger) is another difference to be considered. The experimental plots might be compared to the first set of a multiple set irrigation. During the early cutoff irrigation experiments, after the experimental plots were irrigated, and inflow to those borders was terminated, the water could be diverted and stored in a reservoir to irrigate other crops (Bali, et al., 1999). On a larger scale, upon terminating the irrigation of one set, the commercial farmer would need to divert the water to another set. As previously noted, the early cutoff method relies on the ability to control water flows from the head ditch to the field, so an allowance must be made for successive irrigation of additional fields downstream (unless an on-farm reservoir is available). Adequate irrigation of the final set could result in additional runoff, and could require an additional delivery of water, a finish head. Application of the finish head could also result in additional tailwater.

Supply canal fluctuations could further increase problems with the last irrigation set. Even if cutoff times are adjusted for inflow fluctuations, and successive adjacent areas were irrigated, time changes would accumulate and could greatly impact the irrigation of the final set. Depending on the cumulative net change, the final set could experience a higher than normal tailwater figure or a higher than normal portion of the field inadequately irrigated.

Coordinating these events, including ordering and applying a finish head if needed, would require increased farm management and increased irrigation labor costs to properly manage these multiple set irrigations.

Water Savings Estimates. Average tailwater during these experiments was only about 1.7% of applied water. This has been variously interpreted as demonstrating that the early cutoff irrigation method can reduce tailwater to, depending on the source, less than 2%, less than 3% or less than 5%, without affecting yields. However, the experimental results are insufficient to support such claims.

Payne and Brown (2003, page 8) illustrate their point that it is important to match the water inflow rate to conditions of each border by citing computer simulations made of the irrigation conditions for several fields monitored by the NRCE group (NRCE, 2002). These simulations showed, they report, that with proper selection of the inflow rates and cutoff times, that tailwater could be reduced to 4%, 4%, 6% and 3% on NRCE Fields 1, 2, 6, and 7 respectively. Even by selecting the very best inflow rate, after the fact, and held constant in simulation, the runoff figures they report are on average 2-1/2 times the average runoff values achieved during the experimental trials.

Payne and Brown (2003, page 5) also cite experience with early cutoff irrigation practice in IID. Over a two-year period between 1982 and 1984, tailwater was monitored on almost 15,000 acres using the early cutoff technique. Payne and Brown note: "During the program, the average measured tailwater spill was 14 percent." Research on approximately 15 acres for 3 years produced tailwater values below 2%. However, commercial use of similar irrigation practice produced tailwater values of 14%, fully an order of magnitude larger.

It is also worthy of note that more than half of the experimental early cutoff irrigation events failed to completely irrigate the field (see Table 5 above). Twelve of 23 Sudangrass irrigations, and 17 of 33 alfalfa irrigations (52% overall) showed less than 100% of the field irrigated. The worst shortages were 87% for the 6/2/97 Sudangrass irrigation and 93% for the 6/7/97 alfalfa irrigation. These correspond to areas at the field end of 163 and 88 feet respectively. For those Sudangrass irrigations covering less than 100% of the field, an average 5% (63 feet) was left dry. For those alfalfa irrigations covering less than 100% of the field, an average 2.5% (32 feet) was left dry.

These differences are large enough to be noticed, and farmers and their irrigators would no doubt react to these observations. As IID farmer Gilbert (2003) suggests, "if an error is to be made in irrigation cutoff, the farmer must err on the side of over-application of water to ensure that the entire field receives adequate water. If a portion of the field is under-irrigated, and dry spots remain, the farmer must make a difficult decision whether to risk crop loss on the under-irrigated area, or re-irrigate the much larger area of adequately irrigated crop, and risk over-irrigation damage to those areas of the field that were already properly irrigated."

This it is reasonable to presume that in commercial practice, farmers using the early cutoff technique would conclude that the cutoff estimation process tends to underestimate the cutoff time (about half the time), and misses the mark by a significant (i.e., very visible) amount. They would probably respond by increasing the estimated cutoff times - by perhaps 5% or 10%. A 5 % increase in estimated cutoff times would have reduced the occurrences of incomplete irrigation in the research experiments from 29 to 6. However even a 10% increase in estimated cutoff times would not have eliminated all incomplete irrigations (two Sudangrass irrigations showed coverage below 90%, so even a 10% increase in cutoff time would leave these fields incompletely irrigated). Increasing the estimated cutoff time would reduce incomplete irrigation at the cost of increasing tailwater on those irrigations that already covered, or nearly covered, the field.

Computer simulations using the SRRP program were provided for a few example irrigation events in various project reports (Bali, et al., 1997, 1998, 1999). These simulations show that increasing cutoff time beyond the "ideal" runoff minimizing cutoff time is accompanied with a nearly proportional response in relative runoff. This is illustrated in Figure 2.

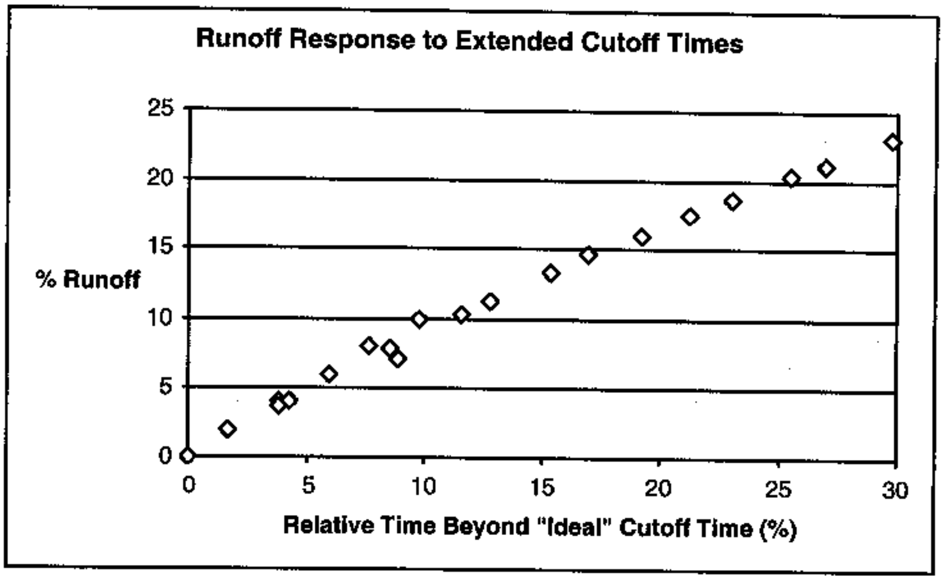

Figure 2. Effect of Extended Cutoff Times on Runoff, Based on SRRP Simulations by Bali, et al., (1997, 1998, 1999).

Assuming for the sake of simplicity that runoff percentages are equal to the relative increase in cutoff time beyond the "ideal" cutoff time (Figure 2 suggests that this is approximately true, at least within the 0 to 10% range), the irrigation results of Table 5 can be used to estimate the tailwater runoff that would occur if farmers increased the cutoff time predictions by 5% or 10%. The results of these calculations are summarized in Table 6.

Table 6. Estimated Effect of Cutoff Time Estimation Methods on Average Runoff (%)

	Cutoff Time Estimation Method		
	Recommended Time	Recommended Time + 5%	Recommended Time + 10%
Sudan Irrigations	1.7 % runoff	4.9% runoff	9.2% runoff
Alfalfa Irrigations	1.7% runoff	5.5% runoff	10.4% runoff

The early cutoff irrigation method as adjusted to eliminate or minimize incompletely irrigated field ends is likely to produce runoff of 5% to 10%, even under experimental conditions. Of course, this calculation is speculative. Without commercial scale demonstrations of the early cutoff irrigation technique, it is impossible to know for sure how typical IID farmers would react to a runoff minimizing technique that also left the lower ends of their fields noticeably dry about half the time. But without such commercial scale demonstrations, it is equally impossible to know for sure that the early cutoff irrigation technique in actual practice would result in runoff values as low as reported for these experiments.

The IID/MWD conservation program has established the fact that water conservation volumes must be determined as the net savings associated with a particular project or practice. Direct savings credited to some practices may be partially offset by a related increase in water use somewhere else. Silva (2003, page 16) notes that some practices have increased canal spills, but nevertheless achieve net conservation with larger reductions in on-farm use.

Applied to the early cutoff irrigation experiments, this lesson directs us to look at the net result of possible runoff reduction along with other related water uses. Differences between the conditions of the experimental plots and commercial practice in the areas of water supply flexibility and variability, multiple set irrigations, and management response to dry field ends are all reasons to expect increased water uses for possible canal spills, runoff from the final irrigation set, or to eliminate dry field ends. Additionally, if yields do decline in commercial practice of this technology, then additional water may be needed to eliminate, or at least reduce, water stress. If possible yield declines are salinity related, then extra water may be needed for periodic additional leaching. All of these should be figured into estimates of possible net water savings.

The early cutoff irrigation experiments themselves provide insufficient grounds to conclude that the technique as applied commercially would achieve tailwater reductions to less than 2%, 3% or even 5%, without affecting yields.

<u>Sustainability</u>

Do the experimental results justify claims that the early cutoff irrigation technique can be used over the long term, without increasing soil salinities or requiring additional water for leaching to prevent an increase in soil salinities?

The Bali, et al. (1999) draft final project report summarize the effects of the early cutoff irrigation method on soil salinity as follows:

> "An increase in soil salinity at the lower end of the alfalfa field was observed as a result of the upward movement of water from the saline water table. However, soil salinity levels after leaching and planting a salt sensitive crop (sweet corn)

> were at or below salinity levels at the beginning of the experiment. Soil salinity in the Sudangrass field did not increase as a result of the implementation of the runoff reduction irrigation method." (page 51)

However, the question of the long term viability of the method remains. A strong warning is offered by MWD expert Walker (2003a, page 4):

> " ... [termination] of the inflow soon enough to eliminate or minimize the tailwater. [This] will generally result in inadequate watering and leaching at the lower end of the field, and while it is an alternative, it does not appear to this writer to be realistic over the long term."

A single 3-year cycle is probably not enough to establish the long term sustainability of the method. Some farmers in IID engage in a longer crop rotation cycle - for example, 4 years of alfalfa and a seed cutting the fifth year (Bradshaw, 2003). The WAC (2003, page 145) also cites a 5-year crop rotation. The performance of the early cutoff irrigation technique for longer crop rotations has not been tested. IID farmer Leimgruber (2003) comments:

> "Any short term study is flawed because it fails to take into account long-term consequences that must be considered by all farmers in the Valley. For example, any farmer can drastically reduce tailwater over a short, three-year period. These farmers may even be able to keep yields up for short periods. However, this will result in severely inadequate leaching of salts from the soil and if proper leaching is not achieved after this period through the use of even more water, the soil will become unusable. The long-term consequences of such a circumstance would be devastating to any farmer." (page 5)

Several possibilities exist, and present evidence is insufficient to prove that any particular one of them is correct.

It may be that long term, the early cutoff irrigation method is sustainable as is.
It may be that it is sustainable, but requires periodic amounts of additional water for salt removal.
It may be that the sustainability of the method is tied to the tailwater reductions achieved - with no or very little tailwater, problems at the lower ends of fields could develop, but at somewhat higher tailwater levels, the practice is sustainable.

Without longer term trials, and commercial demonstrations on the variety of the conditions found in IID, the long term sustainability of the early cutoff irrigation method remains an open question.

Costs

The cost estimates prepared by Kleinman (2003) and Payne and Brown (2003) assume that the early cutoff irrigation method could be adopted by commercial IID farmers with very little change from the way it was used during the experimental trials. However, differences in conditions for the research experiments and for commercial farmers in IID suggest that these cost estimates fail to include some significant cost considerations for commercial use of the early cutoff irrigation method. These include:

Credit is given for tailwater reductions (water cost savings) that are greater than may be actually achieved in commercial practice
Inadequate consideration is given to related additional uses of water such as:
- spills
- extra runoff from final irrigation sets
- extra water to eliminate incompletely irrigated field ends,
- extra water to relieve possible water-stress- related yield reductions, and
- extra water for possible periodic leaching needed for sustainability

Inadequate consideration given to potential yield losses, which may well exceed the 5% "worst case" assumed by Kleinman
Insufficient costs for the "greater attention" required by farm managers and irrigators required to successfully implement this method
Insufficient costs for irrigation labor for night time shift differentials
No costs included for on-farm regulating reservoirs
No costs included for additional training and education
No costs for the type of demonstration and extension program requested by Reclamation
No costs included for irrigation district support

Thus their cost estimates provide insufficient justification for Reclamation's claim that the "early cutoff practice is simple and inexpensive" (Johnson, 2003, page 52).

Summary

There are significant differences between the conditions of commercial practice and the conditions of the early cutoff irrigation experiments of Bali and Grismer. These differences argue against the assumption that commercial scale results when using this method will be similar to the experimental results obtained. Research experimental results provide insufficient justification to conclude that when implemented in commercial practice, the method will achieve:

Little or no tailwater
No additional water use required for related purposes
Little or no effect on crop yield
Long term sustainability
Minimal cost increases to the farmers

Commercial demonstrations under the range of conditions typical in IID are necessary to establish the viability of the method for:

Border lengths greater than 1250 feet
Commercial field conditions

Water orders of either 12- or 24-hour

Commercial demonstrations under the range of conditions typical in IID are necessary to establish for commercial scale implementation:

Appropriate net water conservation targets for early cutoff irrigation
Appropriate costs to commercially implement early cutoff irrigation
Expected yields under early cutoff irrigation
Practices to best implement early cutoff irrigation with a water supply of limited flexibility
Practices to ensure the long term sustainability of early cutoff irrigation

BLOCKED ENDS SIMULATIONS

Walker (2003a, 2003b) used the SIRMOD III computer simulation program to simulate alternate irrigation strategies for irrigations on several fields monitored by the NRCE group (NRCE 2002). The program was calibrated to fi the average data presented by NRCE. Following calibration, the program was used to simulate the irrigations as reported by NRCE. A series of re-designed field options were also identified, and simulations of potential irrigations on the re-designed fields were made. The computer model was also used to investigate the consequences of unsteady delivery rates to the efficiency and uniformity of farm irrigations. Walker's conclusions from this work include the following:

> [Regarding cracking clay soils] "most of the water added to the root zone via cracks is due to normal infiltration processes within a temporarily increased contact area. The results of the calibration analyses indicate that special considerations of soil cracking in terms of depression storage are not necessary."
>
> "The average leaching fractions [of the irrigations on the NRCE-monitored] fields ranged from 3% to 20% while the distribution of leaching over the field lengths ranged from 0% to almost 30%. While the uniformity of the water application is generally high, the leaching is not."
>
> "… even when average leaching fractions are below the threshold indicated by the salinity in the irrigation water, substantial parts of the field may be adequately leached even during mid-season irrigations. The corresponding distribution of leaching during other irrigations, particularly any pre-plant and post-plant irrigation's would be likely to be more effective in leaching near the upper and lower ends of the field. Consequently, over periods of cropping seasons and cropping rotations, the uniformity of leaching may be substantially different than indicated by simulating the NRCE evaluations."
>
> "It should be noted that diking the downstream end of the field does not completely eliminate tailwater as water may need to be released after a given length of time to prevent scalding."
>
> "Simple blocked-end border irrigation [requires] a small 200 foot strip of the field at the lower end … with an adjusted slope of 0.0005 … [would cost] about

$13/acre ... [and could] control tailwater within 5% of headgate diversions [and] would not increase either the area under-irrigated or under-leached."

"[Re-designed] fields were re-leveled to have the lowest 400-800 feet graded to 0.05% ... [at a cost] of about $50/acre ... [and could] limit tailwater to 5% of headgate diversions [and achieve] average leaching of 8.5%."

"When the IID deliveries fall short of the required flow, the deep percolation, and thus leaching increases proportionately. As the delivered flow increased, the opportunity for leaching decreases. Controlling tailwater to a 5% limit is possible but would require the irrigator to shutoff the inflow at different times."

Do simulation results indicate expected results under commercial practice? As indicated previously, the process of technology development and transfer to commercial practice consists of many activities, accomplished over time. The following four stages represent a simple categorization of these activities:

1. Conceptual and theoretical development
2. Research experiments
3. Commercial-sale demonstrations
4. Commercial practice of the technology

At each stage, the technology may be refined or adjusted based on information gained during the preceding stage. The environment surrounding implementation of the technology is different during each stage, so results obtained at each stage do not necessarily apply (without modification) to the next stage.

Conceptual and theoretical development will identify and apply the appropriate scientific and mathematical principles, and may result in computer models or suggested field practices. Theoretical results usually don't consider such real world factors as differences across space and time of important properties, or the imprecision likely in the measurement or estimation of key values, or the possibility that simplifying assumptions are "too simple" for real world conditions. Comparing theory against field measurements can provide a check that such real world factors are not so significant that they invalidate field application of the technology.

Walker's simulations of possible irrigation practices for IID are clearly at Stage 1 in this sequence. The simulations use a single, simplified infiltration function that is assumed to apply equally over the simulated border, assumes no cross-border variability, and assumes no "real world" complications with the scalding release required to prevent crop damage from excessive ponding.

In evaluating the extent to which Walker's simulated results can be extrapolated to commercial field practice, it is useful to review the theoretical and research results for the early cutoff irrigation method, and possible adjustments which might occur in commercial practice.

The Grismer and Tod (1994) volume-balance-based method to predict the cutoff time necessary to minimize runoff is analogous to a simulation model to select cutoff times to both eliminate tailwater and fully irrigate the border. Research results under small scale and ideal water supply conditions resulted in from 0 to 7% runoff (average 1.7%) and less than complete irrigation of the field about half the time (see Table 5). Adjusting the cutoff time estimation method in an attempt to eliminate incompletely irrigated fields could increase average runoff to from 5% to 10% (see Table 6). Commercial practicalities of water supply and multiple set irrigations could reasonably be expected to further increase estimates of runoff rates that might be achieved commercially. Limited practical experience with a similar irrigation methodology in 1982-1984 produced average measured runoff of 14% (Payne and Brown, 2003, page 5).

Bali and Grismer (1995) checked simulated surface irrigation performance on a cracking clay soil, based on the Kostiakov and modified Kostiakov infiltration equations against field results. The simulated irrigation performance values did not match well the field measured values. The workers concluded:

> "Simulated application efficiency and distribution uniformity of second and third irrigation were drastically lower than the measured ones. The simulation model overestimated the average depth of infiltration during the last two irrigations when compared to field data. Modification of the infiltration function to account for the presence of cracks is needed to accurately predict border irrigation system performance in clay soils." (Bali and Grismer, 1995, page 5)

Walker's simulations did not use an infiltration function modified to account for the presence of cracks (2003a). In his later work (2003b) he compared the effects of different infiltration functions on simulated leaching distributions, but apparently did not re-run his earlier simulations.

That Walker was able to simulate adequate leaching with only 5% tailwater, in the computer, "by adjusting inflow rates, set times, and by leveling the lower end of the fields (2003a, page 5)" does not prove that this same tailwater limit could be achieved in commercial practice. The simulation runs adjusted parameters in the computer to optimize a single simulated irrigation event. The degree of flexibility this implies is not always available to commercial farmers. Franzoy (2003) notes that slopes cannot be changed significantly without redesigning the farm ditches and perhaps affecting the performance of the tile drains. As discussed above, the IID water supply is characterized by a certain level of inflexibility and variability. Walker's simulations of delivery rates above and below the "design" value show that even in simulation, controlling tailwater to a 5% limit is only possible if the irrigator adjusts the cutoff times to match the actual delivery rate.

There are other practical issues with commercial implementation in IID that could prevent achievement of Walker's 5% tailwater target in practice. The Walker simulations include a "scalding protection release" to release the water ponded behind the blocked ends after a given length of time to prevent scalding. Knowing the time to activate the scald release is a critical, and somewhat fuzzy, issue.

As Gilbert (2003) notes, "water does not always flow through a field or furrows uniformly, or in a predictable manner." The experimental irrigations of Bali and Grismer sometimes show both an incompletely irrigated field and some runoff, suggesting cross-border variations in advance. Since watering different positions across the border may reach the field end at different times, deciding when ponding starts is a judgment call. Deciding when to activate the release depends on knowing how long water may pond without crop damage, and on how long it will take the ponded water to drain off the field once the release is activated. The reduced slope on the bottom of the fields will slow this drain-off process. Given the great potential for scald damage with blocked ends, irrigators will tend to activate the scald release earlier rather than later. For this reason alone, simulated tailwater estimates are better characterized as a lower bound on what may be achieved under ideal conditions, rather than an upper limit on the tailwater that should be tolerated when blocked ends are implemented in practice.

Until the blocked ends technique is demonstrated in commercial fields, under realistic soil, field scale, water supply and irrigation labor conditions, there is no way to quantify the tailwater that may reasonably be expected with this method. Differences between the ideal conditions inherent in blocked ends simulations and the less flexible, more variable conditions encountered in commercial practice are significant. It is unlikely that the 5% runoff rate hypothesized by Walker, or assumed by Payne (2003b) would be achieved in commercial practice.

In general, current estimates of cost per unit volume of water conserved for this method are low. The 5% tailwater of the Walker simulations is a lower bound on probable tailwater, not a value that can be expected to be achieved in commercial practice. The Payne and Brown (2003) estimate of costs for blocked ends (pages 9-10) includes only a minor cost ($0.35/acre) to block the ends of the field, and release the ponded water at the designated scald release time. No additional cost for irrigation labor is included. More significantly, no land grading costs are included, even though Walker has estimated an average cost of $13/acre to flatten the last 200 feet of the field for the simple blocked-end irrigation system he simulated. Payne and Brown (2003, page 25) estimate a cost of $13/acre to level the bottom third of the field, even though Walker estimates $50/acre to flatten the bottom 400-800 feet of the field. Walker's costs themselves may be low, since they were based on an earthmoving cost of $0.50 per cubic yard, and Franzoy (2003, Tables 1, 2 and 3) cites earthmoving costs of $0.68 to $0.74 per cubic yard according to IID-area contractors.

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